HEALTH EFFECTS INSTITUTE

STATEMENT

Synopsis of Research Report 199

Vehicle Emissions Characterization in Tunnels in Hong Kong and Baltimore, Maryland

INTRODUCTION

Traffic emissions are an important source of urban air pollution, and exposure to traffic-related air pollution is known to be associated with various adverse health effects. Emissions from motor vehicles have changed substantially over the last few decades because of new fuels, changes in engine designs and operation, and improved emission control technology. Tunnel studies allow for characterization of real-world emissions from a large fleet of in-use motor vehicles, and a series of studies in the same traffic tunnels can be used to characterize changes in the emissions of the motor vehicle fleet over time.

In this study, Dr. Xiaoliang Wang and colleagues from the Desert Research Institute sought to evaluate how mobile-source emissions have changed through real-world emissions characterization in two traffic tunnels that had been studied in the past: the Shing Mun Tunnel in Hong Kong and the Fort McHenry Tunnel in Baltimore, Maryland. They measured a large suite of more than 300 pollutants and used the data to derive fleet-average, pollutant-specific emission factors; they then compared their results with previous studies in the same tunnels and elsewhere. In addition, they established VOC and $PM_{2.5}$ source profiles and differentiated between tailpipe and non-tailpipe $PM_{2.5}$. Lastly, they evaluated the performance of mobile-source emission models used in the regulatory process by comparing the modeled emission factors to the emission factors measured in the tunnels.

APPROACH

This study evaluated changes in mobile-source emission factors since 2003–2004 in the Hong Kong Tunnel and since 1992 in the Baltimore Tunnel. The tunnels represent two locations with very different fleet compositions, emission controls, fuels, and near-road air pollutant concentrations (Statement Table). These tunnels were selected for the current study because they had been intensively studied previously. The earlier studies were conducted prior to recent changes in regulations, technologies, and fleet composition that were expected to reduce

What This Study Adds

- This study measured emissions of more than 300 pollutants in 2015 from motor vehicles in two tunnels — the Shing Mun Tunnel in Hong Kong and the Fort McHenry Tunnel in Baltimore, Maryland.
- The measured emission factors for light- and heavy-duty vehicles for most pollutants were markedly lower compared with earlier studies in the same tunnels although increased use of liquefied petroleum gas in Hong Kong appeared to result in increases in emissions of certain pollutants.
- The Hong Kong regulatory emissions model generally agreed with measured emissions. However, the United States regulatory emissions model used in Baltimore estimated emissions that were substantially higher than measured emissions for most pollutants, suggesting that the model is significantly overestimating actual on-road emissions.
- All of the data collected in the current study are available online (see Additional Materials 1 on the HEI website). They will be very useful in tracking past as well as future changes in motor vehicle emissions and in updating and evaluating emissions models used in the regulatory process.

This Statement, prepared by the Health Effects Institute, summarizes a research project funded by HEI and conducted by Dr. Xiaoliang Wang, Desert Research Institute, Reno, Nevada, and colleagues. The complete report, *Real-World Vehicle Emissions Characterization for the Shing Mun Tunnel in Hong Kong and Fort McHenry Tunnel in the United States* (© 2019 Health Effects Institute), can be obtained from HEI or our website (see last page).

Statement Table. Sampling Conditions and Descriptive Characteristics of the Shing Mun Tunnel and Fort McHenry Tunnel

Parameters	Shing Mun Tunnel	Fort McHenry Tunnel
Location	Hong Kong, China	Baltimore, Maryland, United States
Earlier sampling periods	August 2003 and January–February 2004	June 1992
Current sampling periods	January–March 2015	February 2015 and July–August 2015
Description of tunnels	One bore in each direction, with 2 lanes per bore	Two bores in each direction, with two lanes per bore and trucks directed to the right-most bores
Fleet composition	2003–2004: 9% liquefied petroleum gas, 41% gasoline vehicles, 50% diesel vehicles 2015: 13% liquefied petroleum gas, 45% gasoline vehicles, and 42% diesel vehicles	1992 and 2015: Left bore: <3% heavy-duty (mostly diesel) vehicles and >97% light-duty (mostly gasoline) vehicles Right bore: 55% to 92% light-duty vehicles and 8% to 45% heavy-duty vehicles
Traffic volume	~53,000 vehicles/day in both 2003–2004 and 2015	~55,000 vehicles/day in both 1992 and 2015
Pollutants measured	*Continuous:* CO, CO_2, NO, NO_x, VOCs, $PM_{2.5}$, SO_2, BC, PNC *Integrated*: NH_3, VOCs (C2–C12), carbonyls, PAHs, $PM_{2.5}$, road dust	*Continuous*: CO, CO_2, NO, NO_x, VOCs, $PM_{2.5}$, UFP size distribution *Integrated*: NH_3, VOCs (C2–C12), carbonyls, PAHs, $PM_{2.5}$, road dust, CO, CO_2

the emissions of air pollutants from motor vehicles. Therefore comparison of the new data obtained by this project with historical data allows for assessment of changes in emissions over time.

The investigators measured concentrations of a large suite of pollutants at the entrance (or air inlet) and exit of each tunnel in the winter (both tunnels) and summer (Baltimore tunnel only) of 2015. They counted and classified vehicles passing through the tunnels; vehicles in the Hong Kong tunnel were classified as fueled by diesel, gasoline, or liquefied petroleum gas, and vehicles in the Baltimore tunnel were classified as light-duty or heavy-duty. The investigators assumed that the difference in pollutant concentration measured between the inlet and exit of the tunnels was emitted by vehicles in the tunnel. They used this assumption to calculate the fleet-average, pollutant-specific emission factors. They also attributed the emissions of the various pollutants to vehicles in the different categories used for classification.

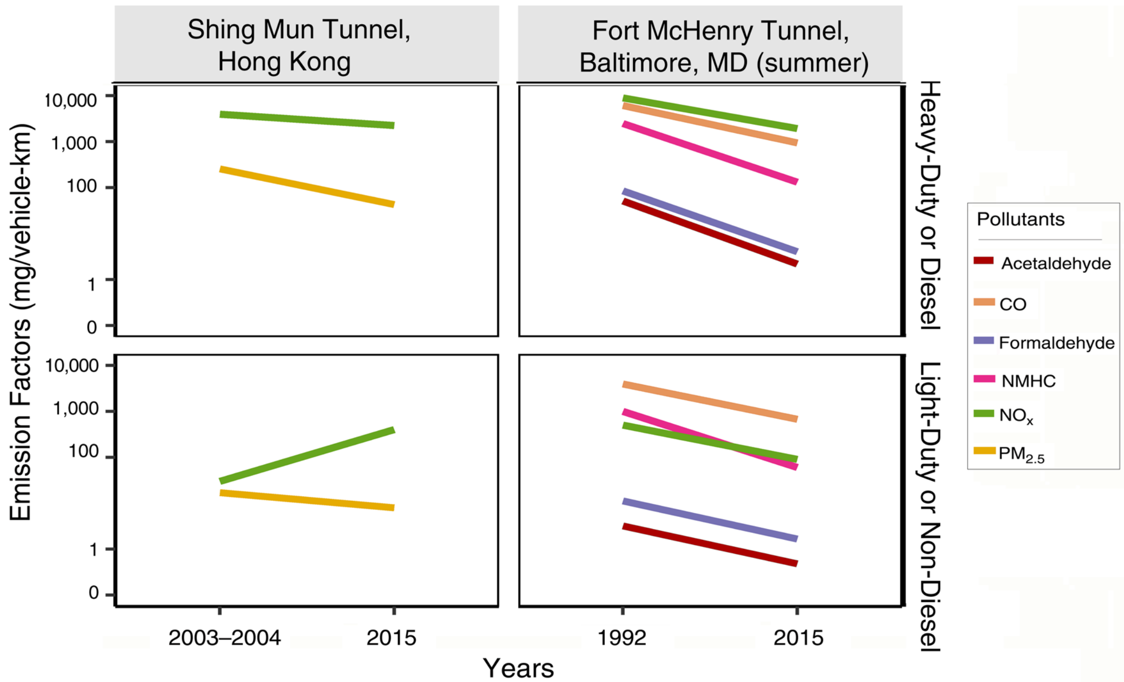
Finally, the investigators put their results in context by comparing them to previously published emissions data. They compared their results with previous studies in the same tunnels and other tunnels in Hong Kong and the United States to explore how vehicular emissions have changed over time. In addition, they evaluated performance of two mobile-source emission models (EMFAC-HK and MOVES) by comparing the modeled emission factors to the emission factors measured in the tunnels.

REVIEW OF THE REPORT

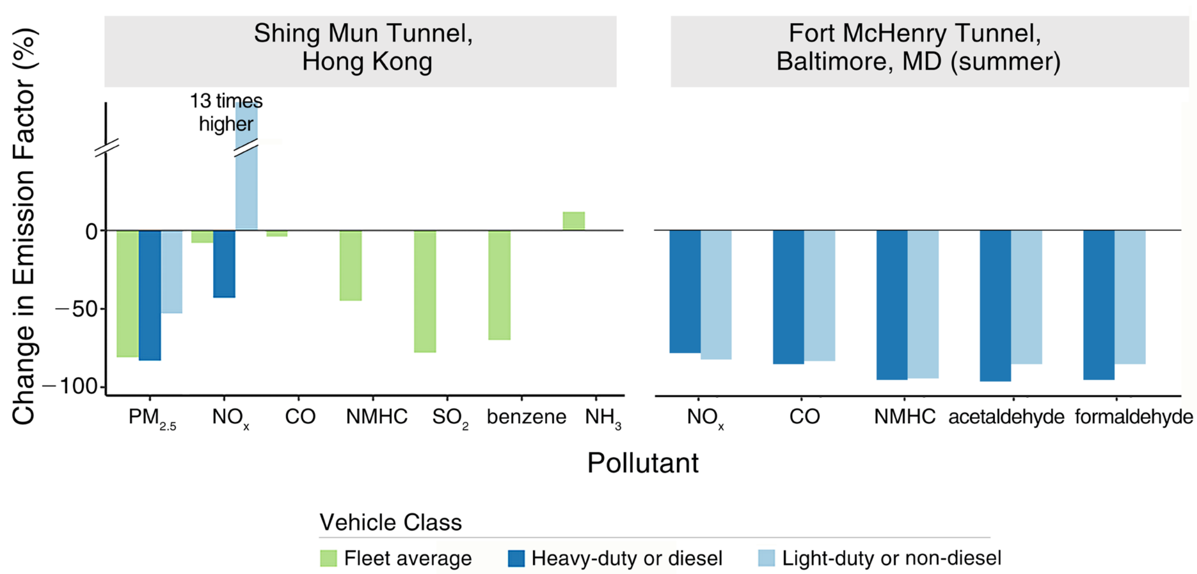
In its independent review of the report, the HEI Review Committee thought that Wang and colleagues had successfully collected a comprehensive set of emissions measurements in two tunnel locations that have been studied before and then used those data to estimate emission factors for the fleet average and for specific vehicle classes. Major contributions of this study were the assessment of emission trends over time, comparisons of measured and modeled emission estimates, and synthesization of results from these multiple data sources. The Committee found that even though the analyses identified uncertainties in some of the results, the major conclusions of the study were sound.

SUMMARY OF RESULTS

An important finding of the study is that the emission factors of most of the pollutants measured in the two tunnels were lower in 2015 than they were in earlier studies in the same tunnels (Statement Figure 1). In the Hong Kong tunnel, the greatest declines in emission factors between 2003–2004 and 2015 were for $PM_{2.5}$, which decreased by about 80% for fleet average and diesel vehicles and was halved for non-diesel vehicles, and for SO_2, which dropped about 80% for fleet average (Statement Figure 2). However, the increased proportion of vehicles fueled by liquefied petroleum gas in Hong Kong resulted in increased emissions of



Statement Figure 1. Emission factors in the Shing Mun Tunnel in Hong Kong and the Fort McHenry Tunnel in Baltimore, Maryland, over time. Not all pollutants were measured in each study.



Statement Figure 2. Percent change in emission factors between 2003–2004 and 2015 in the Shing Mun Tunnel in Hong Kong and between 1992 and 2015 in the Fort McHenry Tunnel in Baltimore, Maryland. Not all pollutants were measured in each study.

certain pollutants associated with that fuel: increased NO_x emissions from non-diesel vehicles were likely related to both the increase in liquefied petroleum gas vehicles and different methods of separating the fleet-average emissions between diesel and non-diesel vehicles in this versus the earlier study.

In the Baltimore tunnel, emission factors of NO_x, CO, NMHCs, acetaldehyde, and formaldehyde from both light-duty and heavy-duty vehicles decreased by 78% to 96% between 1992 and 2015. ($PM_{2.5}$ was not measured in the earlier study.) Much of this difference was related to reductions in emissions from light-duty vehicles. Determination of the relative effectiveness of the regulations for light-duty versus heavy-duty vehicles needs further investigation.

The investigators compared their results to earlier studies in the same tunnels, to other tunnel studies in the same countries, and to models used in the regulatory process in order to confirm their main findings and highlight sources of uncertainty to be explored in future research. Despite the different tunnel configurations and fleet characteristics in the two tunnels, measured changes in pollutant emission factors over time were generally consistent between the two tunnels or explainable by well-understood properties of the vehicle fleets. The model used for the regulatory process in Hong Kong also produced results consistent with the measurements. A notable exception to consistency between measurements and models was that the regulatory emissions model for the United States substantially overestimated the real-world emissions in the Baltimore tunnel. Therefore, future work will be important to understand the reasons for that overestimation in order to develop accurate inventories of actual on-road vehicle emissions.

CONCLUSIONS

Quantifying the contribution of vehicle emissions to ambient concentrations of major pollutants — including $PM_{2.5}$ (and its major constituents), NO_x, and NMHCs — is a topic of interest for scientists and policymakers; therefore, having vehicle source profiles that represent emissions from the current fleet is important. The data collected in the current study (available online) are useful in tracking past as well as future changes in motor vehicle emissions and updating emissions models used in the regulatory process. Quantifying emissions from motor vehicles will continue to be important. As populations grow, urbanization continues, and the density of vehicle traffic in major cities increases, large numbers of people continue to be exposed to traffic-related emissions that affect population health even as emissions from individual vehicles go down, underscoring the role of studies such as this to quantify emissions from motor vehicles.

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